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Aspect and Deviation Angle

by
T. A. Croft

March 1964

Technical Report No. 90

Prepared under
Office of Naval Research Contract
Nonr-225(64), NR 088 019, and
Advanced Research Projects Agency ARPA Order 196-64

RADIOSCIENCE LABORATORY

STANFORD ELECTRONICS LABORATORIES

STANFORD UNIVERSITY · STANFORD, CALIFORNIA

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ABSTRACT

The purpose of this paper is twofold: first, an attempt is made to define "aspect angle" and "deviation angle" in a logical and acceptable manner; second, a graphical calculator is supplied in the hope that it will make the calculation of these angles so simple that the definitions will be used without unnecessary approximations.

When a target is being observed by some means, it frequently happens that the target is associated with some vector of importance, as for example, its heading or velocity. In this case the observer is very often interested in an "aspect angle" which is the angle between the vector of interest and the direction of propagation of whatever wave is used for the observation (e.g., light, radio, sound, etc.). There are three angles associated with this aspect angle which can normally be measured by an observer with ease; the graphs given here can then be used to find the true aspect angle.

Often a target is observed by means of some form of radiant energy which emanates from a source that is distant from both the target and the observer (e.g., bistatic radar). In this case the observer will usually want to know the aspect angles as defined above when calculated relative both to the observer and to the source of radiation. In addition, there is another very significant angle which is defined herein as "deviation angle." It fortunately turns out that the same graphical calculator can be used to determine the deviation angle from three easily calculated angles.

CONTENTS

ILLUSTRATIONS

ACKNOWLEDGMENT

Mrs. R. M. Shanahan carried out much of the mathematical work presented here.

I. INTRODUCTION

Those who work with sound, light, or radar detection systems, wherein aspect-sensitive targets are to be detected, are frequently called upon to solve a geometry problem of moderate difficulty. This problem arises so often that it seems worthwhile to try to solve it, in general, for once and for all. In order to do this, it is necessary to give unambiguous definitions to terms "aspect angle" and "deviation angle." These definitions also will facilitate data comparisons between different observers.

The geometry problem to be solved involves the relationship between four angles. Fortunately, the solution is applicable to the calculation of both aspect and deviation angles. The aspect angle (which is defined for the case of an observer sensing a target associated with some preferred vector) can be found from the enclosed graphs by entering with the values of three angles which are relatively easy to determine. Similarly, the deviation angle (which is defined for an observer who senses a target by the radiation from a remote source) can be found from the same graphs using the values of three other angles which also are easy to determine.

Thus, in this paper eight angles are defined and graphical relations are given between them. It is believed the geometry problem solved here is rather commonly encountered and perhaps the observant reader will find unexpected applications for these graphs.

II. ASPECT ANGLE

Figure 1 shows the four angles that are involved in this discussion. Two vectors are shown: the "raypath" and the "target attitude." The target attitude might represent the direction of target travel or some other vector associated with the target which is believed to affect the observation. The raypath represents the direction of the observer's line of sight when it encounters the target. If the method of detection is by sound or by refracted radio waves, the raypath may not be straight line to the observer and it may be necessary to solve a raytracing problem to find the ray angle, γ. The map angle β can be found when the intersection of the target attitude and the raypath is drawn on a non-distorting map.

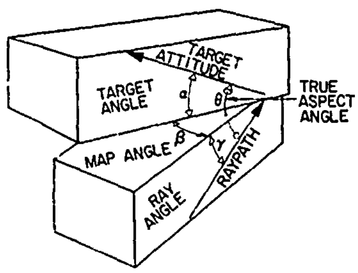


FIG. 1. "ASPECT ANGLE" CALCULATION. (The two blocks are drawn to aid perspective.)

The sense and size of α, β, γ, and θ are defined as follows:

1. α is positive if the target attitude is upward; the magnitude of α never exceeds 90 deg; and α is zero if the target attitude is horizontal.
2. γ is positive if the raypath is going upward as shown on Fig. 1 at the point where it intersects the target; the magnitude of γ never exceeds 90 deg; and γ is zero if the raypath is horizontal at the target.
3. β varies between 0 and 180 deg and no discrimination is made as to whether it is positive or negative; β is zero if the observer is ahead of the target and is 180 deg when the observer is behind the target.

4. θ varies between 0 and 180 deg and no algegraic sign is given to it; like β, θ tends toward zero when the observer is ahead of the target and toward 180 deg when the observer moves behind the target.

Thus, the definitions of α and γ are nearly identical and the definitions of β and θ are nearly identical; only α and γ can have algebraic signs.

To use these definitions, find α, β, and γ for each moment of interest. For each such triplet refer to the graphs of Fig. 3 (pages 5 to 21) and find the two which span the desired value of γ. Enter both of these graphs with the values of α and β and then use a linear interpolation relative to γ in order to determine the true aspect angle, θ. Although it is awkward to describe this process in words, the reader should find that it is quite rapid and easy to carry through.

III. DEVIATION ANGLE

Figure 2 shows the four angles and two vectors involved in the definition of deviation angle. Since the geometry problem that needs to be solved is the same as was involved in the aspect-angle calculation, the same Greek leters will be used. The energy from the source of illumination encounters the target in the direction defined by the "ray from transmitter" vector shown on Fig. 2. The similar path which leads to the observer starts away from the target in the direction shown by the "ray to receiver vector. The direction of these vectors relative to local horizontal is used to define the angles γ and α, both of which are positive when the vectors are upward. (Thus, notice that α is shown negative on Fig. 2.) The map angle β is again defined as it was during the calculation of aspect angle and is shown on the figure. The user may find it more convenient to use the supplement, $180^{\circ} - \beta$. The deviation angle, which is the angle through which the energy is bent by the target, is then the supplement of θ, where θ is found from Fig. 3 by entering with α, β, and γ as before.

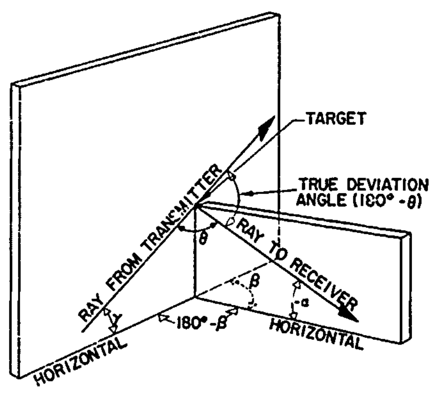
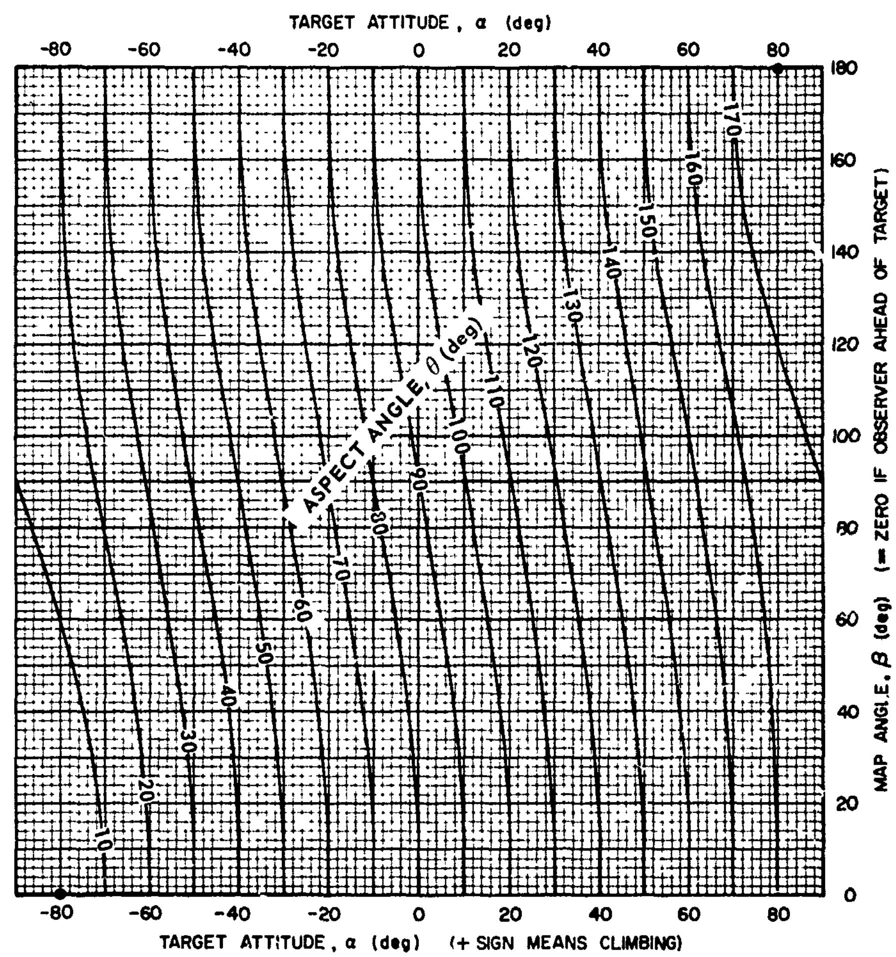


FIG. 2. "DEVIATION ANGLE" CALCULATION. (The two vertical slabs are drawn to aid perspective.)

LINE OF SIGHT IS 80 DEG ABOVE HORIZONTAL

$\gamma = +80°$



(a)

FIG. 3. GRAPHICAL RELATIONS BETWEEN α, β, γ, AND θ.
Parts (a) through (q) are on pages 5 to 21.

LINE OF SIGHT IS 70 DEG ABOVE HORIZONTAL

$\gamma = +70°$

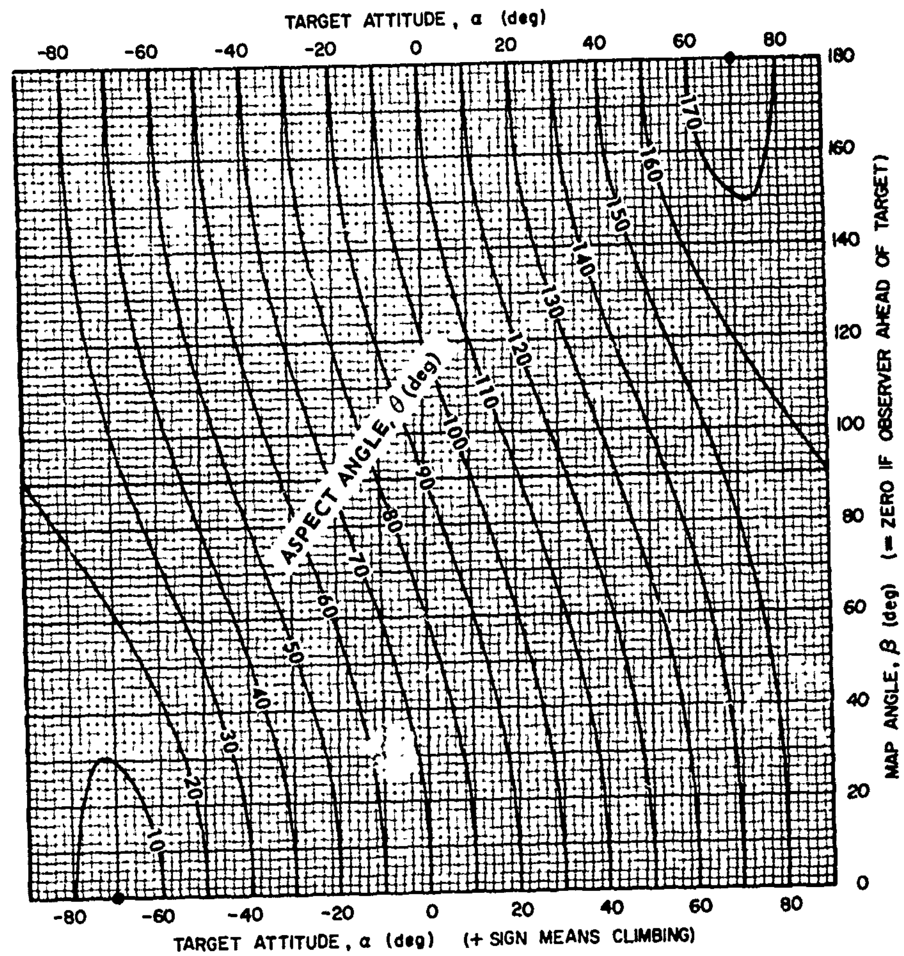


FIG. 3(b).

LINE OF SIGHT IS 60 DEG ABOVE HORIZONTAL

$\gamma = +60°$

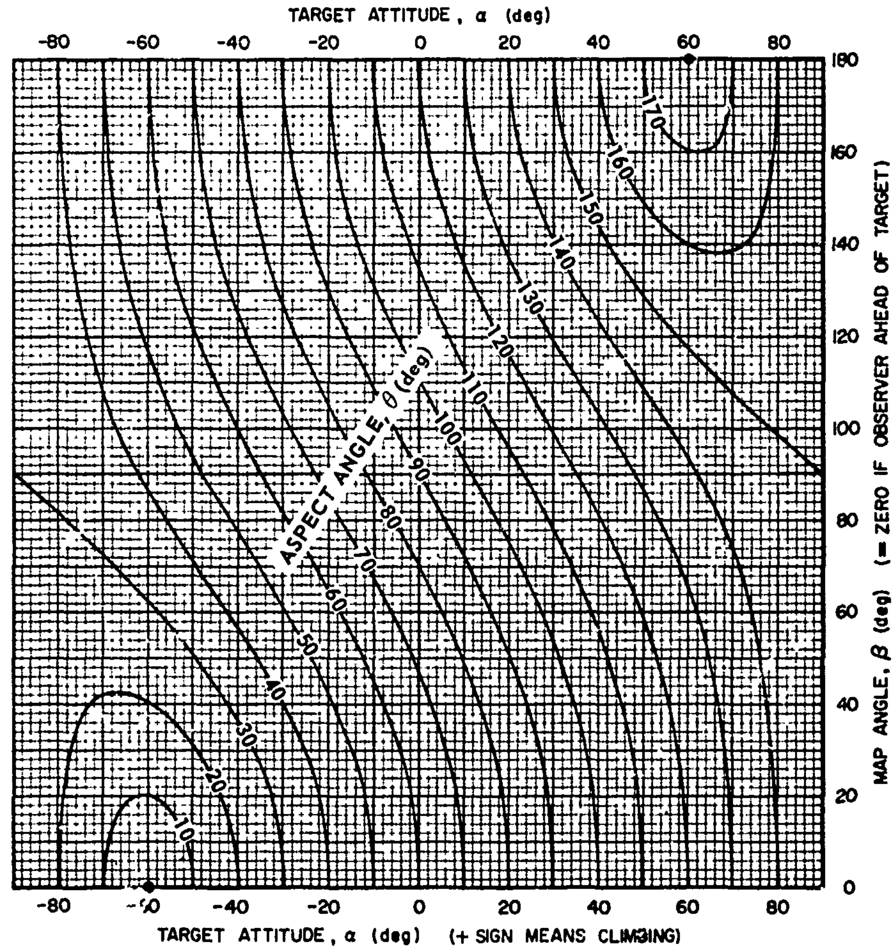


FIG. 3(c).

LINE OF SIGHT IS 50 DEG ABOVE HORIZONTAL

$\gamma = +50°$

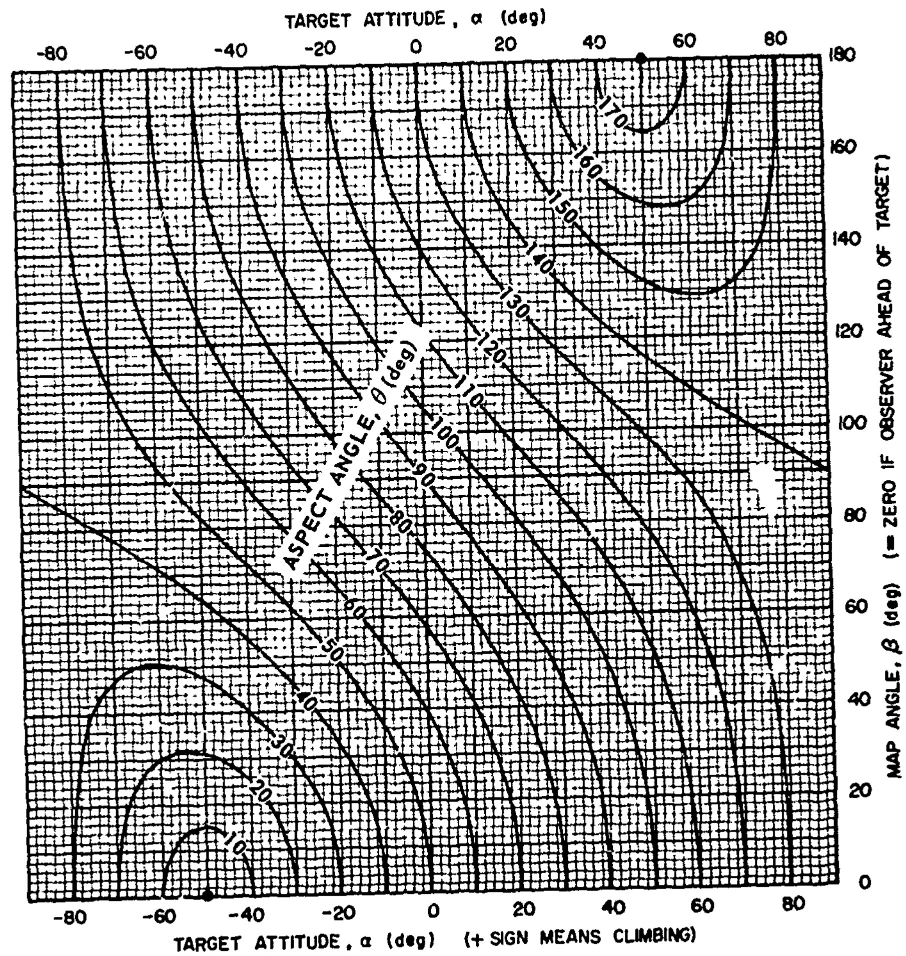


FIG. 3(d).

LINE OF SIGHT IS 40 DEG ABOVE HORIZONTAL

$\gamma = +40°$

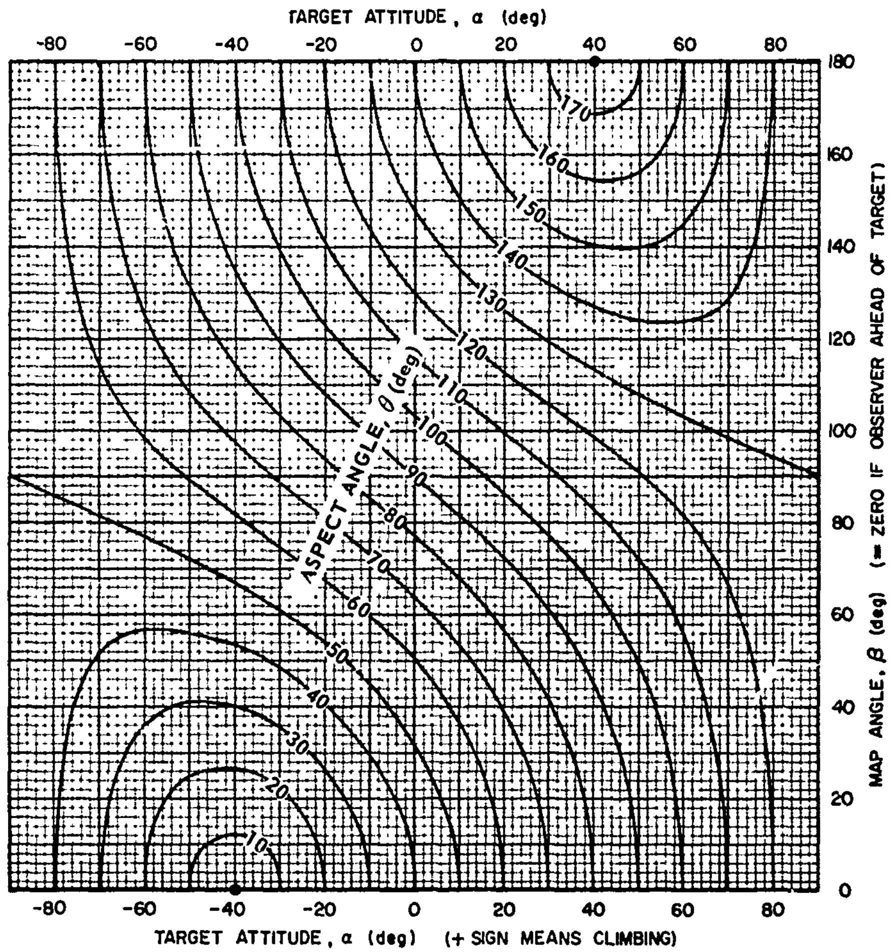


FIG. 3(e).

LINE OF SIGHT IS 30 DEG ABOVE HORIZONTAL

$\gamma = +30°$

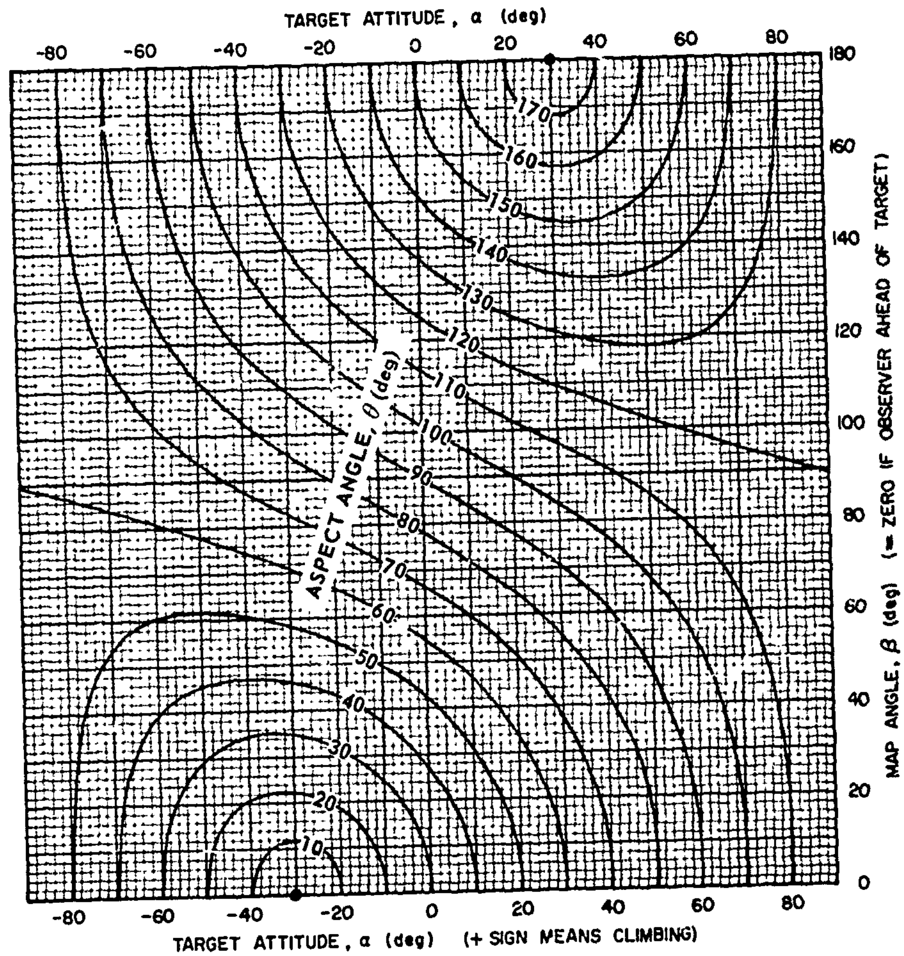


FIG. 3(f).

LINE OF SIGHT IS 20 DEG ABOVE HORIZONTAL

$\gamma = +20°$

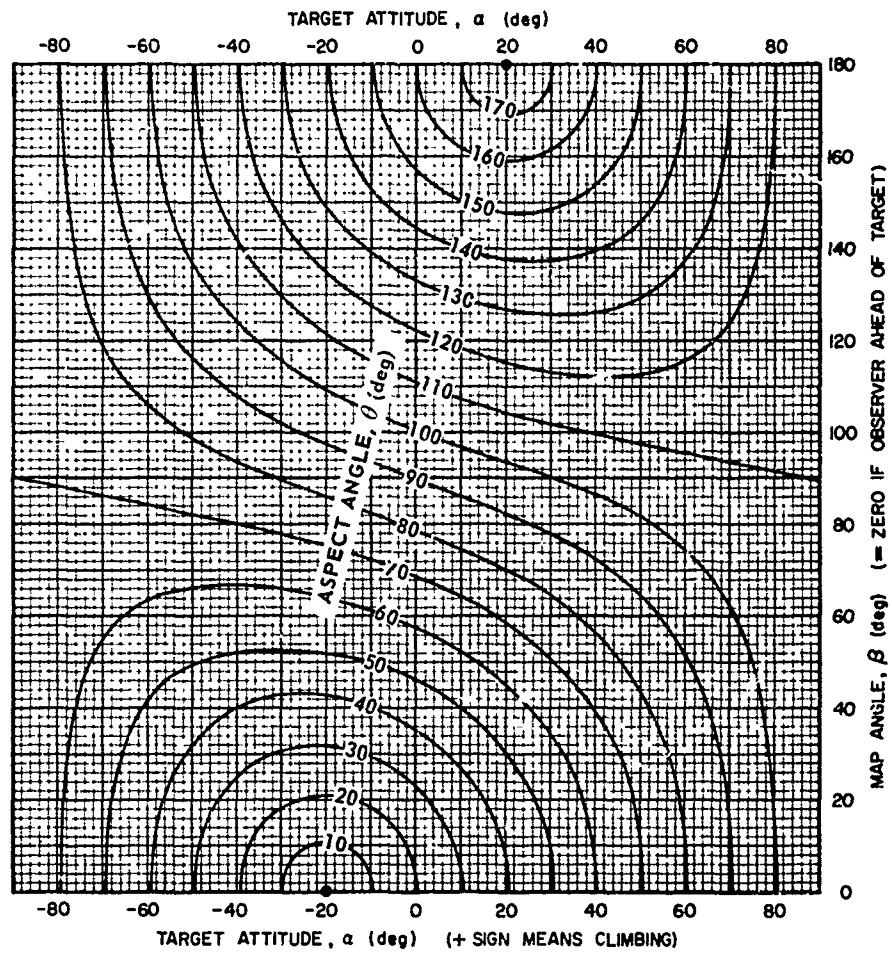


FIG. 3(g).

LINE OF SIGHT IS 10 DEG ABOVE HORIZONTAL

$\gamma = +10°$

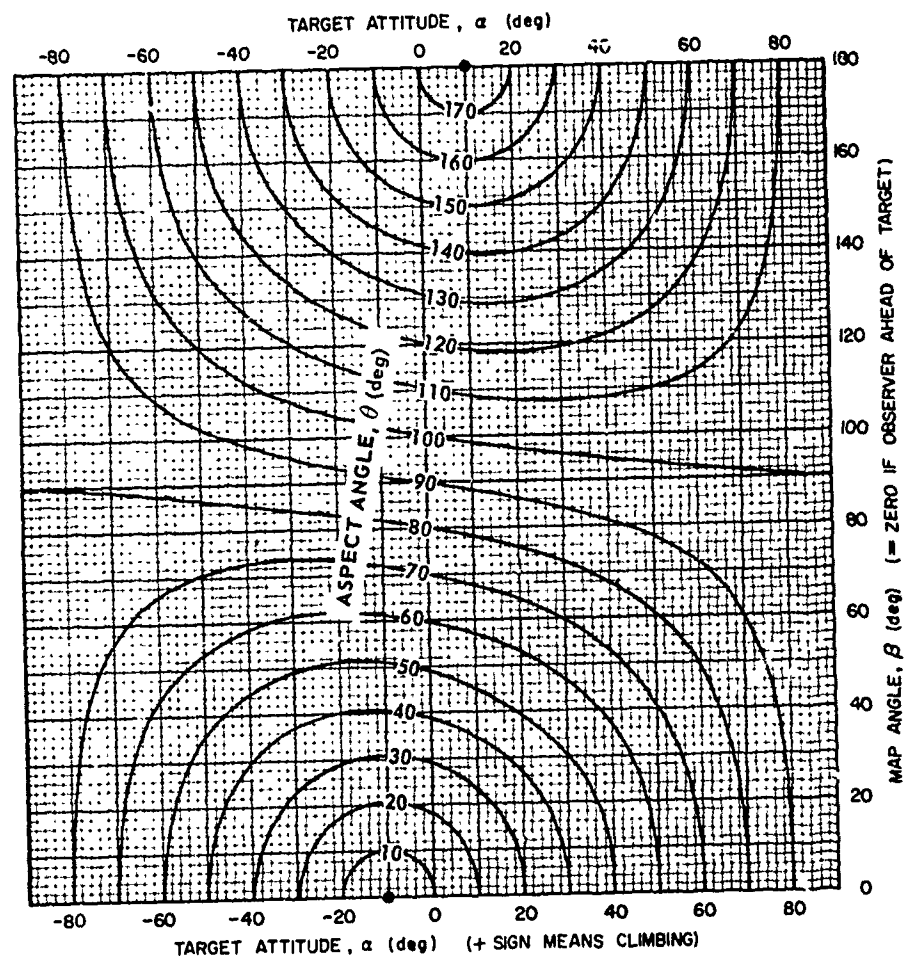


FIG. 3(h).

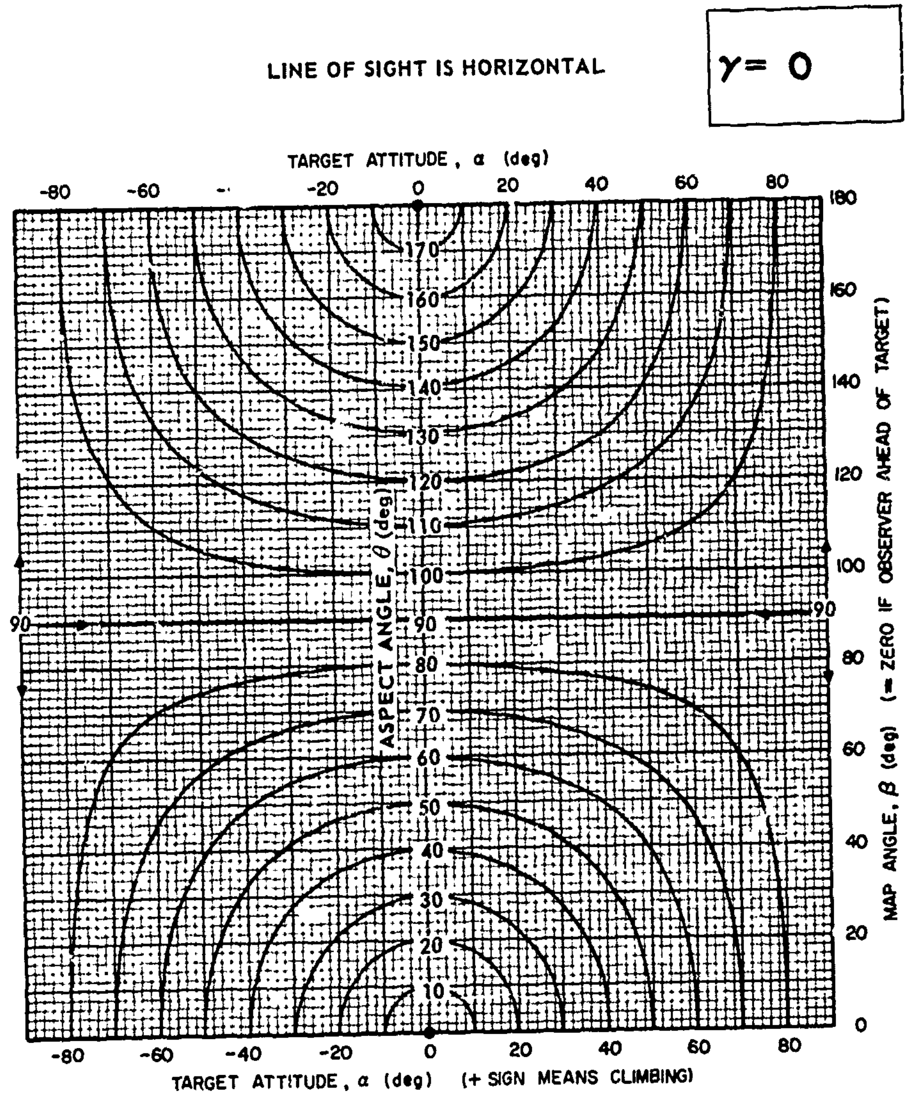

LINE OF SIGHT IS HORIZONTAL
$\gamma = 0$
TARGET ATTITUDE, α (deg)
ASPECT ANGLE, θ (deg)
MAP ANGLE, β (deg) (= ZERO IF OBSERVER AHEAD OF TARGET)
TARGET ATTITUDE, α (deg) (+ SIGN MEANS CLIMBING)
-80
-60
-40
-20
0
20
40
60
80
180
160
140
120
100
90
80
60
40
20
0
170
150
130
110
70
50
30
10

FIG. 3(i).

LINE OF SIGHT IS 10 DEG BELOW HORIZONTAL

$\gamma = -10°$

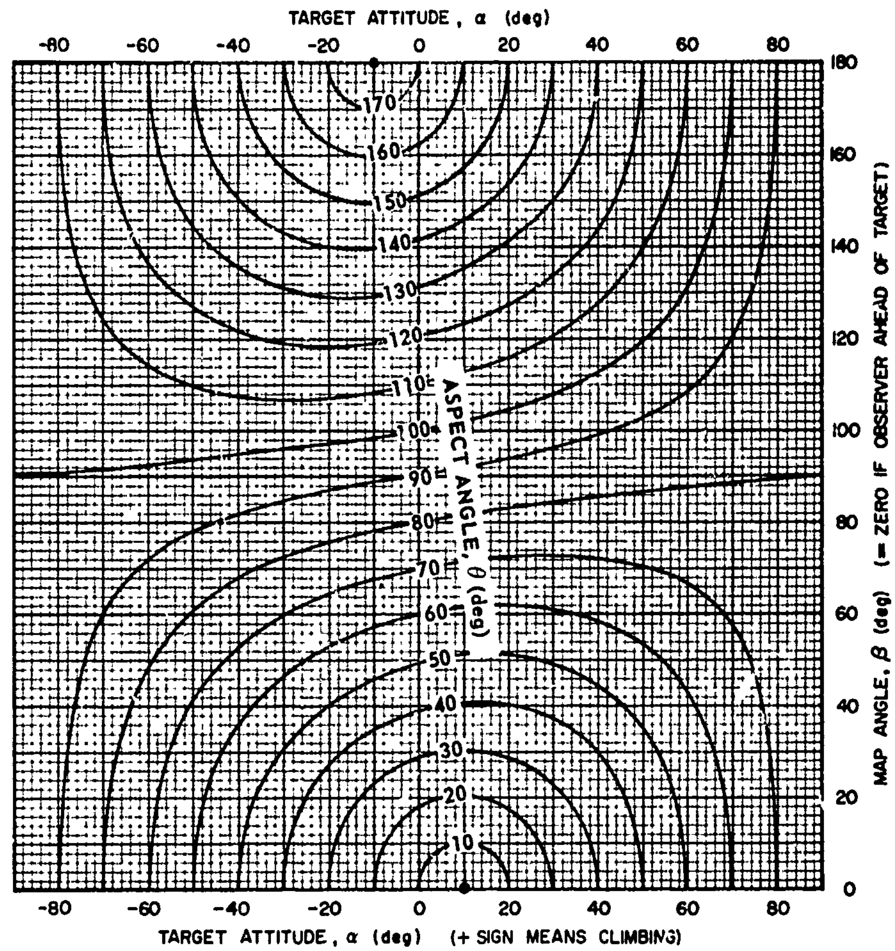


FIG. 3(j).

LINE OF SIGHT IS 20 DEG BELOW HORIZONTAL

$\gamma = -20°$

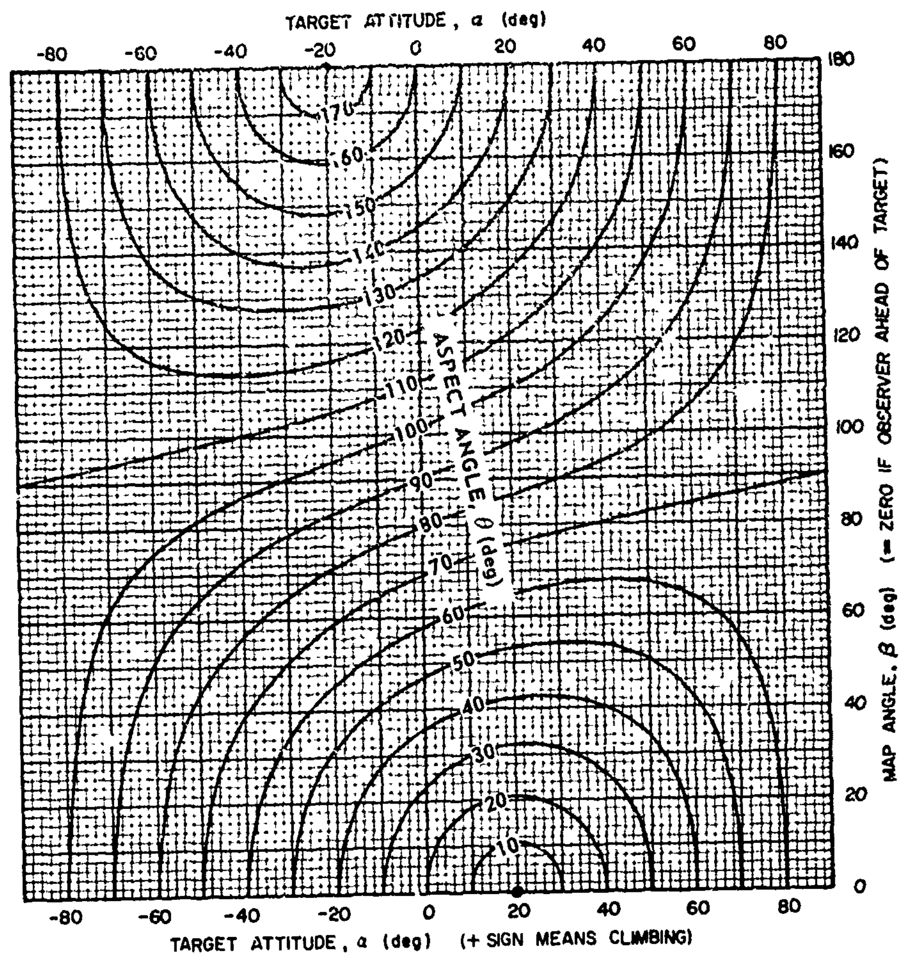


FIG. 3(k)

LINE OF ' '' HT IS 30 DEG BELOW HORIZONTAL

$\gamma = -30°$

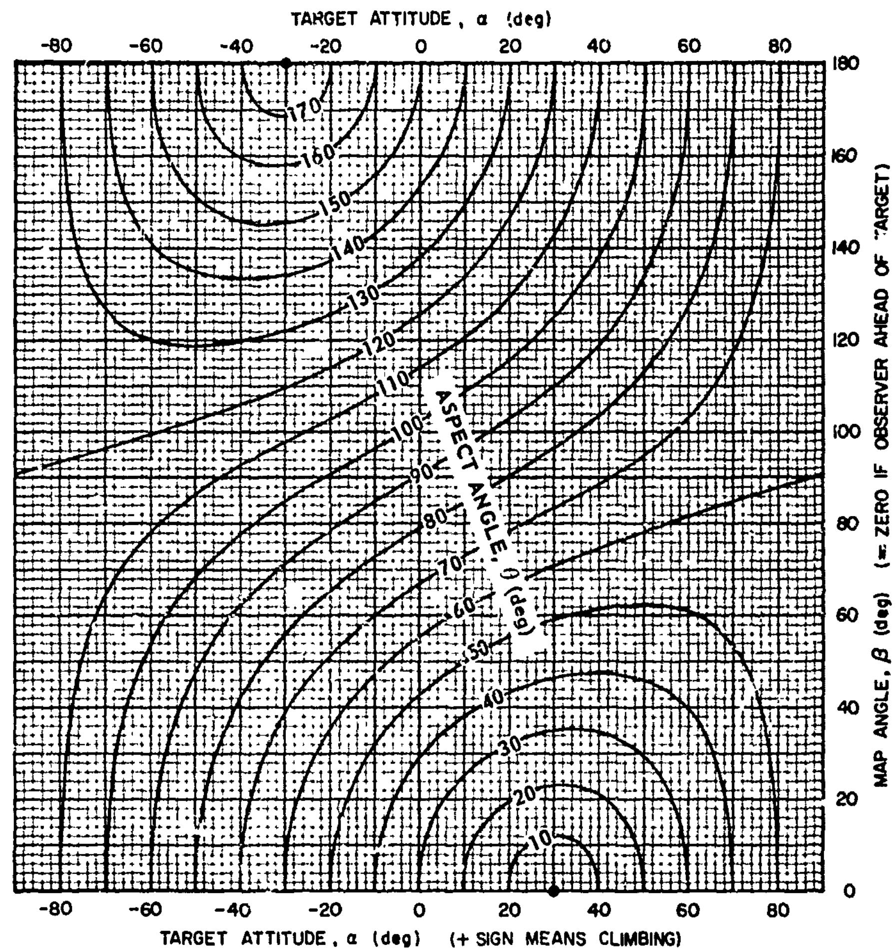


FIG. 3(1).

LINE OF SIGHT IS 40 DEG BELOW HORIZONTAL

$\gamma = -40°$

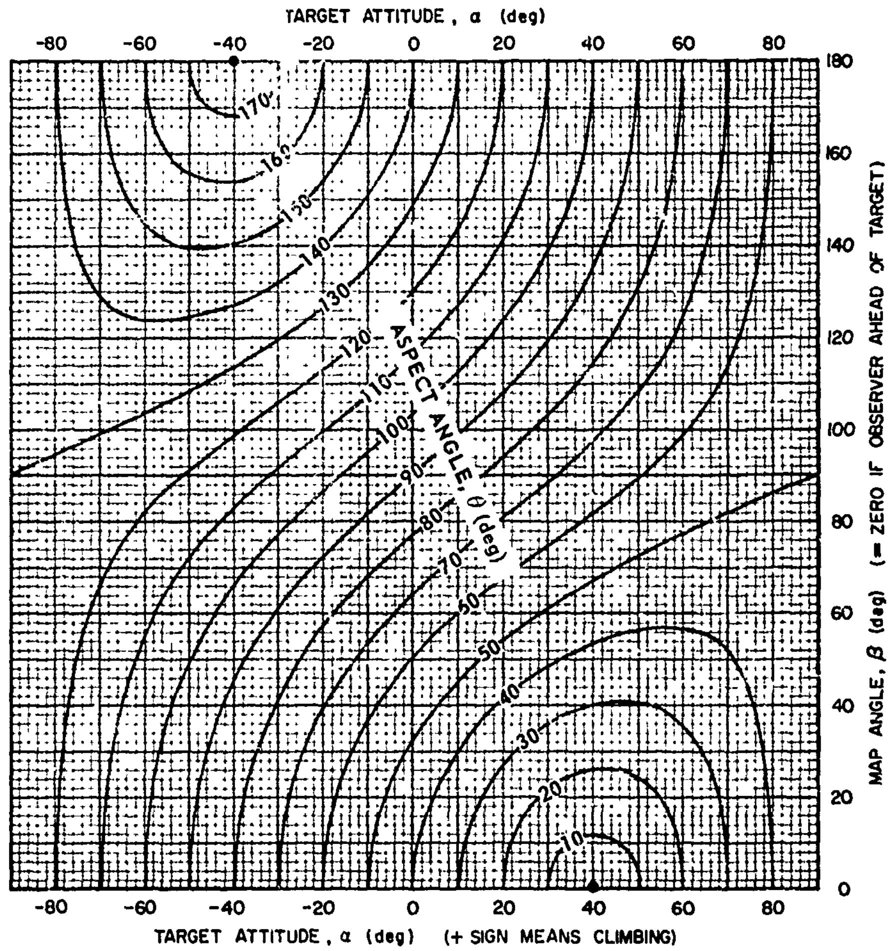


FIG. 3(m).

LINE OF SIGHT IS 50 DEG BELOW HORIZONTAL

$\gamma = -50°$

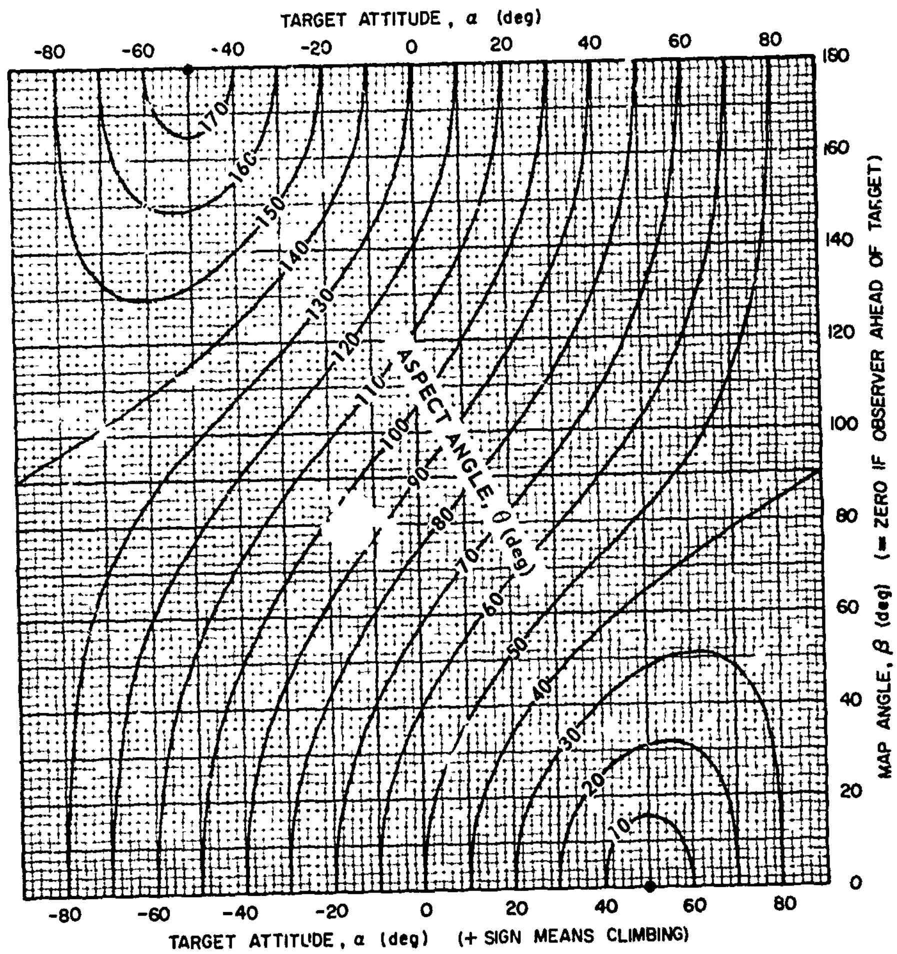


FIG. 3(n).

LINE OF SIGHT IS 60 DEG BELOW HORIZONTAL

$\gamma = -60°$

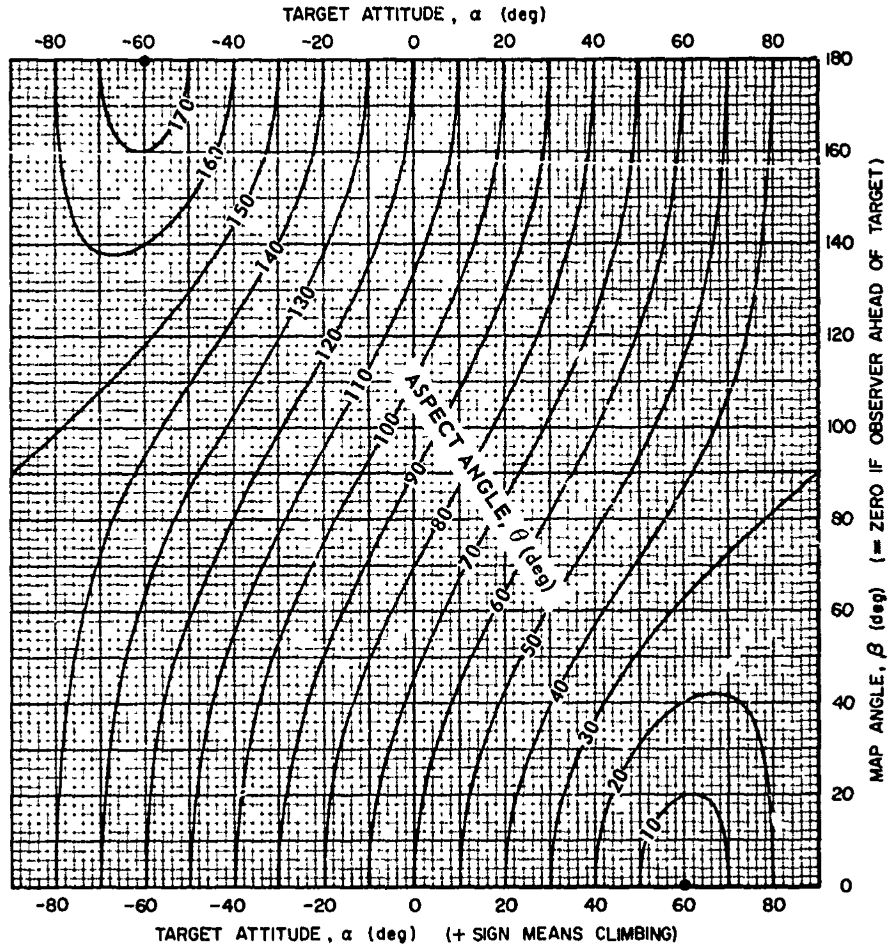
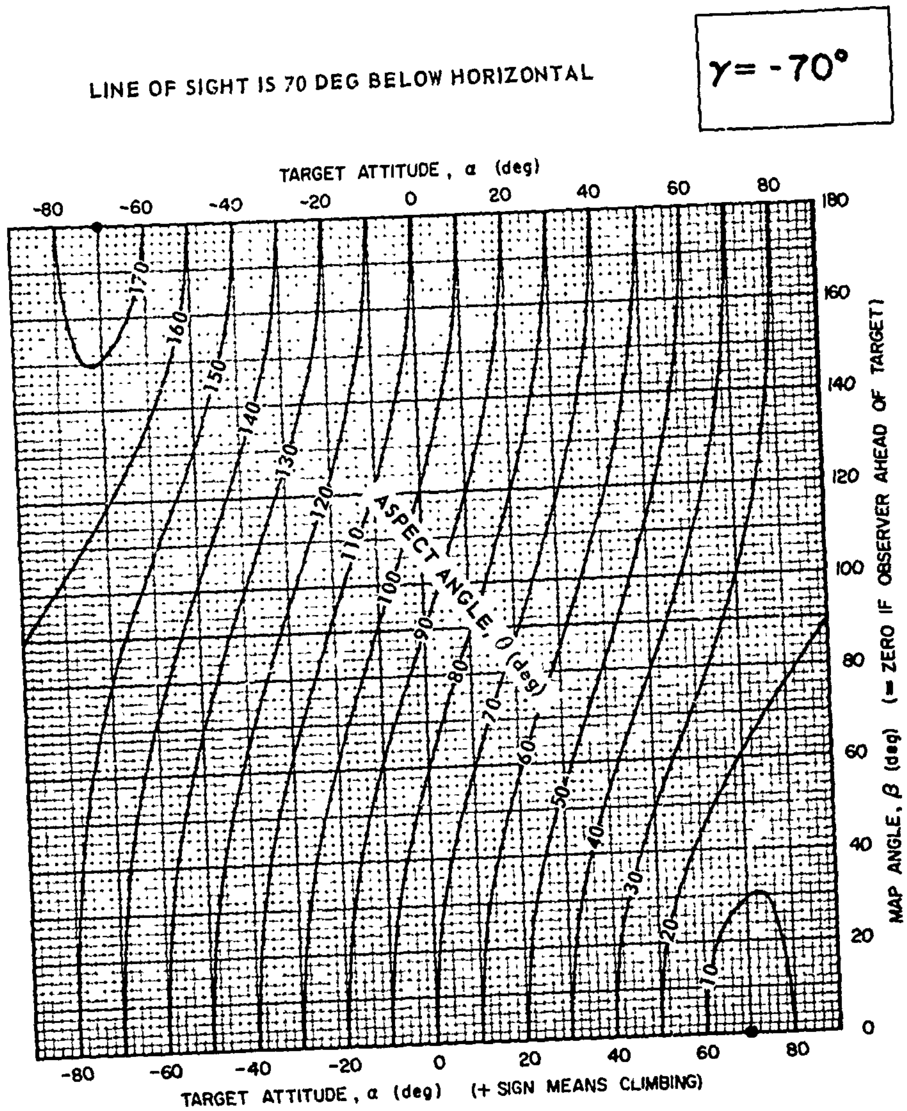


FIG. 3(o).



$\gamma = -70°$
LINE OF SIGHT IS 70 DEG BELOW HORIZONTAL
TARGET ATTITUDE, α (deg)
-80
-60
-40
-20
0
20
40
60
80
180
160
140
120
100
80
60
40
20
0
MAP ANGLE, β (deg) (= ZERO IF OBSERVER AHEAD OF TARGET)
ASPECT ANGLE, θ (deg)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
TARGET ATTITUDE, α (deg) (+ SIGN MEANS CLIMBING)

FIG. 3(p).

LINE OF SIGHT IS 80 DEG BELOW HORIZONTAL

$\gamma = -80°$

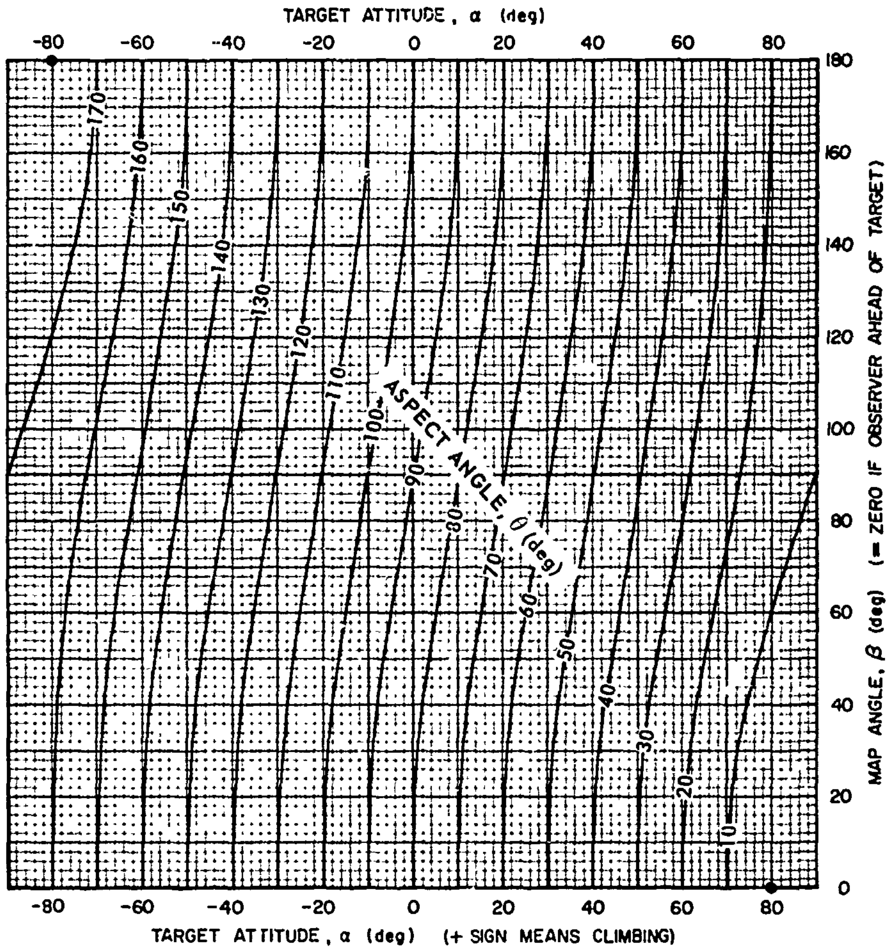


FIG. 3(q).

IV. SOLUTION OF THE GEOMETRY PROBLEM

Figure 4 shows the definitions that are used in this section. Let $A_x = B_x = 1$ and notice that the vector A lies in the x-y plane while the vector B is not so limited. Then it can be seen that $A_y = \tan\alpha$ and $B_y = \tan\gamma \sec\beta$.

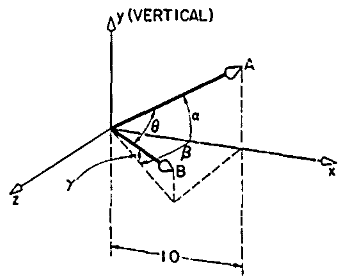


FIG. 4. GEOMETRIC DEFINITIONS.

The lengths of the vectors A and B are:

$$|A| = \sec\alpha \qquad |B| = \sec\beta \sec\gamma$$

Utilizing the definition of the dot product of the vectors A and B, it is found that

$$\cos\theta = \frac{A_xB_x + A_yB_y + A_zB_z}{|A|\,|B|} = \frac{1 + \tan\alpha \tan\gamma \sec\beta}{\sec\alpha \sec\beta \sec\gamma}$$

from which it follows that

$$\cos\theta = \cos\alpha \cos\beta \cos\gamma + \sin\alpha \sin\gamma.$$

As used in this paper, γ is the negative of the angle shown in Fig. 4. In this case, the final result given above would have a minus sign in front of $\sin\alpha \sin\gamma$.

V. CONCLUSION

Aspect angle and deviation angle have been defined, each together with a triplet of more easily accessible angles which are needed for calculation. Graphs are presented which minimize the time needed to find these angles. The derivation of the equations used to produce these graphs was given.

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